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A COMPUTER AIDED DESIGN (CAD) SYSTEM FOR INDUCTION HEATING PROCESS ANALYSES

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A generalized CAD system, developed for induction heating process analyses, integrates several physical processes and provides a realistic simulation tool to assist application engineers in meeting energy conservation goals as outlined in the corporate Demand/Supply plan. This report provides a summary of the CAD system and a brief summary of the results obtained from a sample simulation.

Introduction

Induction Heating is a non-contact heating technology in which electrical current is induced in the work piece to create the required heating. With its capability of providing high power density and easily controllable heating profile, it is widely used in various industries. Its applications include metal heat treatment, brazing, debrazing, soldering, welding, melting etc.

The application of induction heating technology to a particular heating process involves the design of the induction heating system to fulfill the process heating requirement. In most cases, the user faces a non standard application. Hence, the power supply specification has to be determined and the inductor has to be designed with sufficient accuracy to not only minimize the cost of the entire system, but also to avoid gross errors.

In induction heating, the work piece/load forms part of the electrical circuit of the power supply. To select a power supply, the specifications of the power supply frequency, the load power, and the load impedance (as functions of work piece characteristics) are required. All of these parameters may be determined during the inductor design phase.

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Inductor design requires the solutions of the electromagnetic field distribution of the inductor(s) and the resulting temperature distribution in the work piece. These solutions are not easily obtained since material properties play a significant role, and the material properties are, in general, functions of temperature. In addition, temperature is determined by the amount of power input and heat loss (conduction, convection and radiation). Hence, the whole problem is interrelated and it is difficult to provide the solutions analytically.

Empirical approximations and/or prototype testing have long been used to determine system and process parameters. Unfortunately, the art of empirical approximation was possible only for some standard applications. Furthermore, this art, which requires many years of experience to master, is quickly disappearing by the retirement of key people in the growing induction heating industry. Prototype testing, in most cases, is time consuming and expensive to conduct.

With recent advances in computing technology, it is now feasible to design the induction heating process and system numerically. Numerical solutions will provide better estimates of the load power, the frequency, the load impedance, the heating and cooling durations, and inductor designs. Numerical studies will probably be more economical and efficient when the hardware required for experimental testing is not available.

As a part of the corporate initiative for energy conservation and better and wiser use of electricity, studies to investigate the energy efficiency of some of the industrial heating processes and the possibility of optimizing their energy consumption by the use of induction heating are needed. To perform these studies efficiently and economically, a Computer Aided Design system has been developed in Ontario Hydro Research Division to model the electro-heat processes involved in induction heating. This report provides a summary of the CAD system and a brief summary of the results obtained from a sample simulation.

The CAD System

In order to perform a valid analysis, a thorough understanding of several interrelated physical processes is required. Due to the complex work piece geometries and the nonlinear and changing material properties, it is necessary to reduce the physical processes to a set of governing equations. These governing equations together with the initial and boundary conditions are subsequently represented in suitable models to allow for numerical analysis of the physical processes. In this report, only the user-oriented CAD system is described in detail.

The CAD system is based on the Finite Element modelling method, and it consists of four main software packages integrated into one system: 1) METSEL/2, a library of material properties; 2) MAGNET for eddy current analysis; 3) SUPERSAP for thermal analysis; 4) An Ontario Hydro Research developed software package for interfacing and integrating packages 2) and 3). The flow of data through the various packages is shown in Figures 1 and 2. The software packages have been implemented on an IBM 286 compatible system. Reference 1 summarizes the computer system requirements.

FIGURE 1
DATA FLOWCHART FOR
THE LINEAR CAD SYSTEM

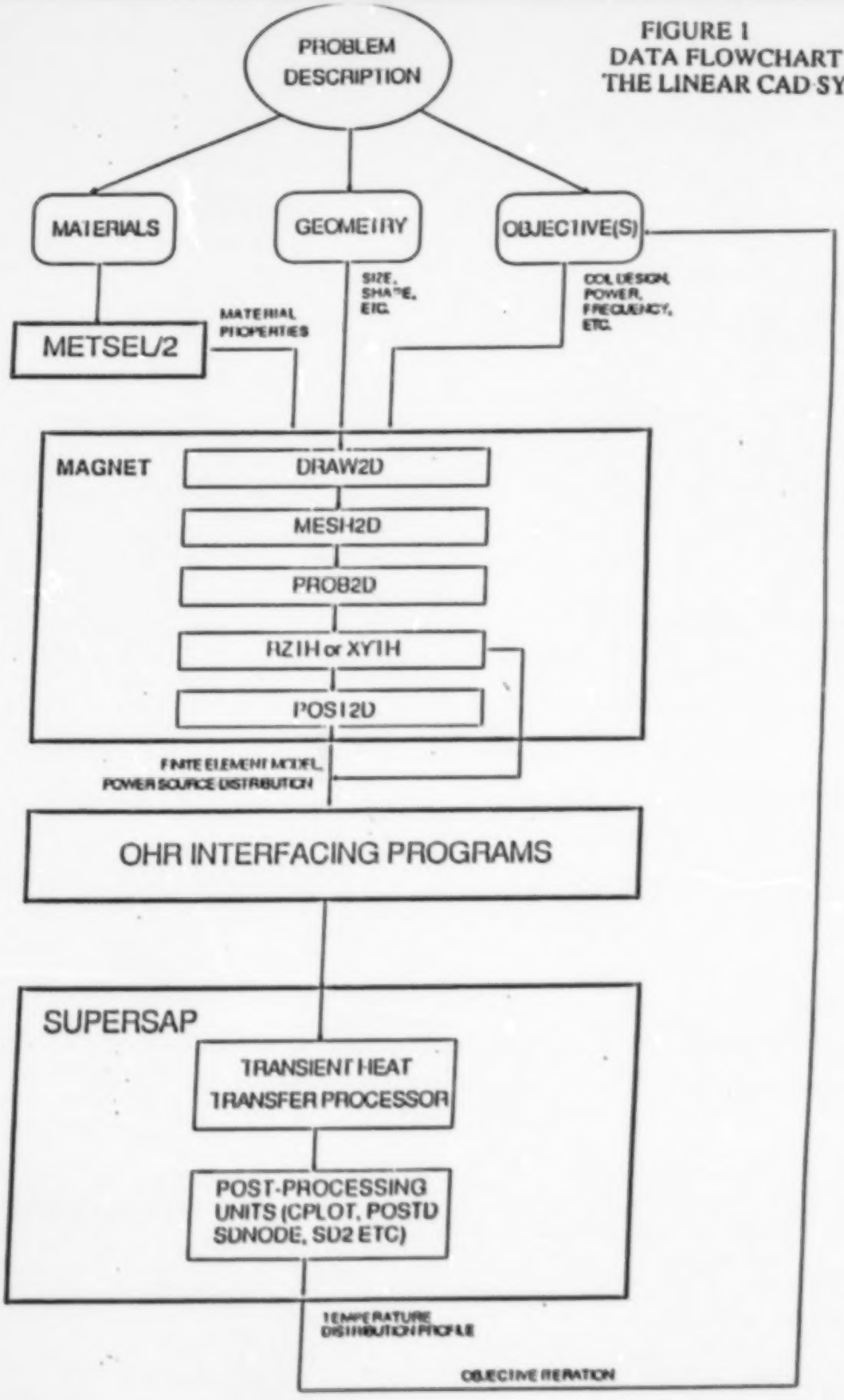
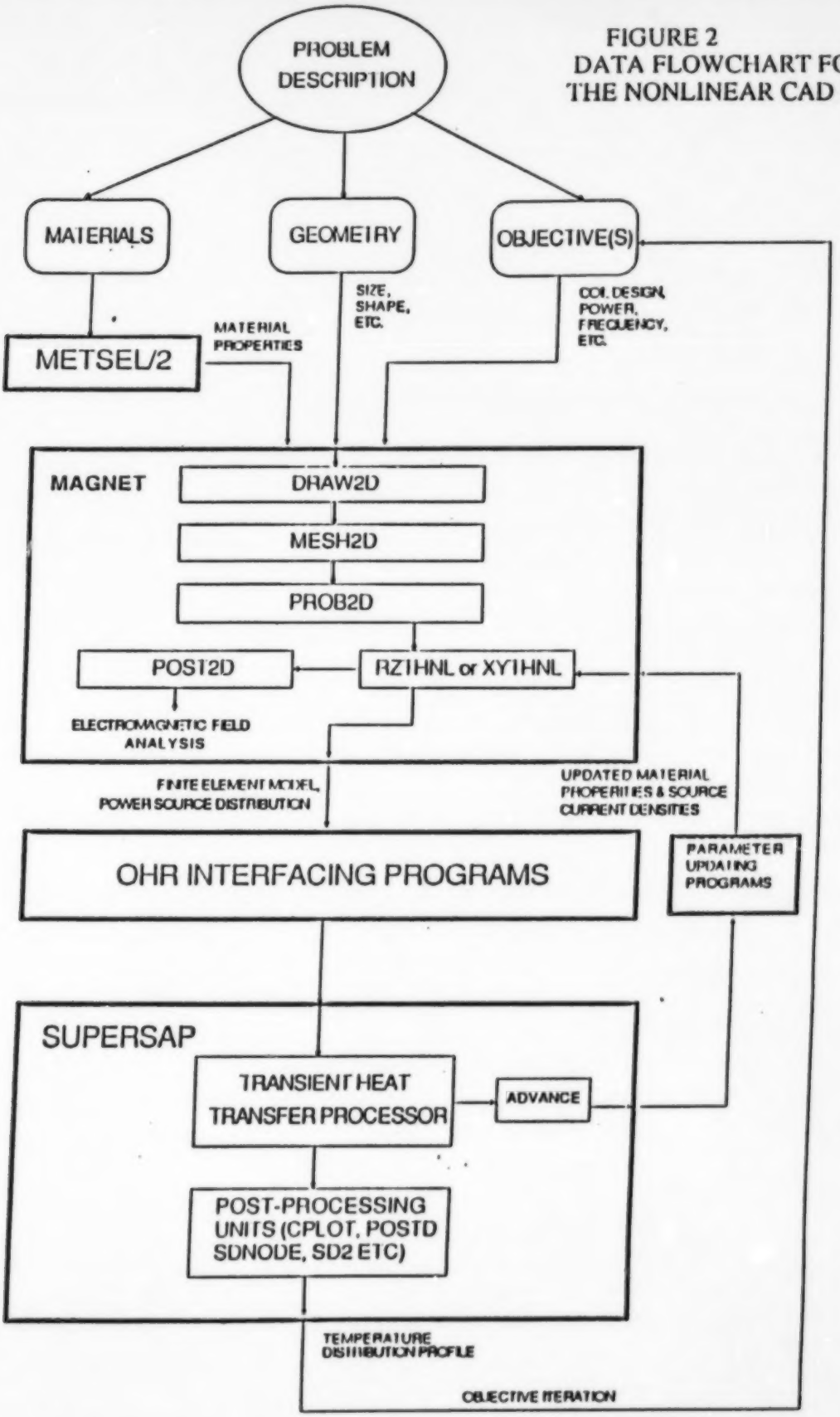


FIGURE 2
DATA FLOWCHART FOR
THE NONLINEAR CAD SYSTEM



The main inputs to the system are the inductor geometries, the work piece geometries and material properties, and the supply current frequency and distributions. The main outputs from the system are the electromagnetic field distributions of the inductor(s), the amount of load power consumption, and the temperature distributions in the work piece.

Types of Analyses

Depending on the geometries of the work piece and the inductor/coil, four types of analyses may be possible:

1) Work piece and induction heating coil with geometries symmetrical around an axis and with linear material properties (linear system);

2) Work piece and induction heating coil with geometries which exhibit no variation normal to a plane and with linear material properties (linear system);

3) Work piece and induction heating coil with geometries symmetrical around an axis and with nonlinear material properties (nonlinear system);

4) Work piece and induction heating coil with geometries which exhibit no variation normal to a plane and with nonlinear material properties (nonlinear system).

User guides for the linear and nonlinear systems can be found in Reference 1. The linear system performs the analysis based on constant input current and work piece material properties, whereas the nonlinear system provides the analysis for varying input current, and updates the work piece material properties as functions of temperature and/or the electromagnetic field strength.

Applications

The system is designed to provide a complete simulation of an induction heating process and may be used for the following applications:

1) Feasibility study of applying induction heating technology to various industrial processes;

2) Induction heating coil design;

3) Specification of a coil's electrical parameters;

4) Frequency selection for an induction heating application;

5) Estimation of power requirement for an induction heating application;

6) Induction heating process design and simulation (coil configuration, frequency, power sequence, heating and cooling profile etc).

A sample simulation

A computer model was constructed to simulate an induction heating process employed in one of the tests conducted by an outside company. The test involved induction heating of a round steel bar. The nonlinear CAD system was used for the simulation. The results, summarized in detail in Reference 1, indicate that the CAD system is useful in providing estimates for the load power consumption and work piece temperature distribution. This information is difficult to obtain/monitor in practice.

The simulated temperature and load power profiles were plotted against the experimental results as shown in Figures 3 and 4, respectively. Useful estimates were observed. The deviations in the surface temperature estimates are believed to be due to the accuracy of the reluctivity data used for the work piece. These data were approximated as they were not readily available. As for the load power profiles, it is believed that the simulated power profile is more accurate than the experimental results since the load power data were measured by using a calorimetric method.

Conclusion

The development of a CAD system for induction heating process design and analysis is completed. This report provides a summary of the CAD system and a brief summary of the results obtained from a sample simulation.

The CAD system has been used for a number of applications during the development phase, and it was found to be very useful. The system can contribute to electric load reduction by providing better designs of existing and/or potential induction heating process & equipment, and the facility for studying the feasibility of replacing potentially energy inefficient heating processes with more efficient induction heating.

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Reference

1 Ng, M.K.C. Ontario Hydro Research Division Report No. E90-23-CON, 1990.

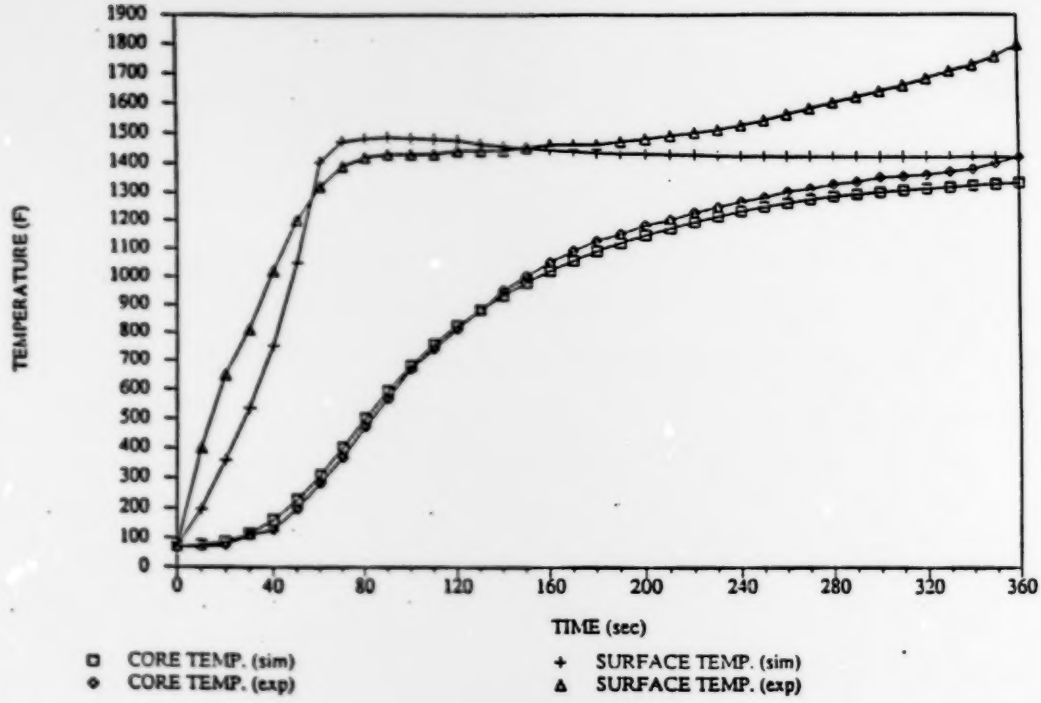

Figure 3
Temperature Profiles
(simulated vs experimental data)

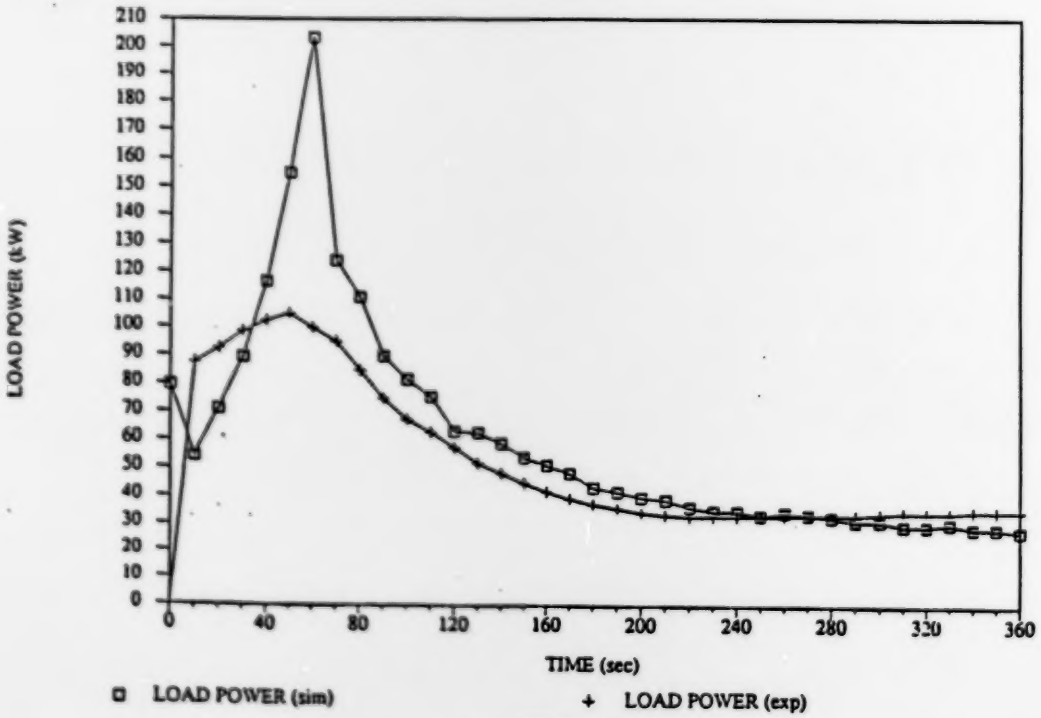

Figure 4
Load Power Profiles
(simulated vs experimental data)